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GROUND ROD METALS - RESULTS OF A THREE-YEAR TEST

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ABSTRACT

The U. S. Naval Civil Engineering Laboratory has been investigating various metals now in use as ground rods, and metals which might be acceptable substitutes. NCEL cooperated with the National Association of Corrosion Engineers by installing a series of test rods ~~at the~~ Laboratory. Test results are given for the second (or three-year) group of test rods from the ~~NCEL~~ test site. The 300 series of stainless steels are recommended for use in grounding systems.

INTRODUCTION

Extensive buried grounding networks are required to establish ground planes for radar installations and radio stations. These networks also serve as grounds for stray currents that would otherwise decrease the efficiency of these facilities. The metal most commonly used for grounding networks at these and other facilities (such as power transformer stations) is bare copper as a solid rod or wire, or as a coating or cladding on a stronger base metal. A serious problem arises when extensive amounts of copper are buried in proximity to a less noble (less corrosion-resistant) metal: corrosion of the less noble metal is accelerated and the second metal eventually fails to perform its primary function.

The Naval Facilities Engineering Command authorized the Naval Civil Engineering Laboratory to investigate several metals which might serve as ground rods. An economically acceptable substitute for copper would be desirable, if compatible with steels or other buried metals, as would alternates for emergency situations when copper was unavailable. The Laboratory then arranged to cooperate with the National Association of Corrosion Engineers in its "Driven Ground Rod Test Program."

A previous report[1] presented NCEL's test program, a description of two test sites (one at NCEL and the second at Point Mugu), and details relative to installation and removal of test rods. Results obtained from the first two groups of test rods were also given. This report deals with data obtained from the second (or three-year) group of rods removed from the NCEL site. A summary of the test program is also included.

TEST PROGRAM

The original installation at NCEL consisted of three groups of test rods. One group was removed after one year, a second group after three years (the subject of this report), and a third group to be removed after seven years in place. All rods were weighed prior to installation; after removal from the ground their corrosion products were to be removed and final weights determined.

1 NCEL Technical Note N-633, "Ground Rod Metals - Results of Two One-Year Tests," by Alfred E. Hanna. 15 October 1964

Test Rods

Each group of test rods, as installed, consisted of thirty-one rods of eight different metal systems. A group includes two sub-groups; the first sub-group consists of single rods of each metal system, while the second sub-group consists of one or more mild steel rods coupled to single rods of the other seven metal systems. The metal systems are mild steel, galvanized steel, Ni-Resist, Type 302 stainless steel, copperclad steel, high-purity zinc, AZ31B magnesium alloy, and No. 6061-T6 aluminum alloy. Single rods of mild steel were coupled to single rods of the other seven metal systems; to provide different anode-to-cathode ratios, two mild steel rods were coupled to single rods of copperclad steel, magnesium, and zinc. The coupled magnesium rods were so badly corroded after one year that they were removed from the test leaving eight couples for further study; the single magnesium rod in each group was left in place.

Data

Types of Measurement. As stated previously, all rods were weighed prior to installation. At the time of installation, each rod's potential relative to a copper sulfate half-cell and its resistance to earth were determined. The same data were obtained for pairs of mild steel rods as soon as they were connected to each other. The potential relative to a copper sulfate half-cell, the resistance to earth, and the current flow were determined for all couples as soon as they were formed. The same data were obtained on a monthly basis thereafter, as conditions permitted.

Significance of types of measurements. Although this study was to determine how well different metals might function if used in buried grounding systems, it was also necessary to learn how these metals would affect or be affected by other buried metallic structures.

The in-place determination of the corrosion of buried metallic structures is almost impossible without a further disturbance of the environment. However, certain methods exist which give an indication of the rate at which a metal is corroding. One method is to determine the potential of the structure relative to a particular reference electrode, such as a copper sulfate half-cell. With steel, for example, a potential of less than 850 millivolts negative to the half-cell is generally taken as an indication of the existence of a corrosion problem. A potential between 850 and 1000 millivolts negative to the half-cell indicates that the structure is not undergoing significant corrosion. A potential difference greater than 1000 millivolts (generally with the structure under some form of cathodic protection) often is accompanied by gas formation, which may have a harmful effect on the structure.

A second method is to measure the current flow between parts of the structure. Where galvanic corrosion occurs a current path is set up between two or more parts of the structure; as the current flows, one part corrodes at a rate proportional to the magnitude of the current. If this method is to be used, a shunt may be installed in the current path for ease in

measuring current flow. An alternative is to establish one or more locations where the current flow can be momentarily interrupted, and to periodically measure current flow at such locations.

A third method, long used in checking electrical grounding systems, is to determine the grounding metal's resistance to earth. A build-up of corrosion products around the rod may be indicated by an increase in the resistance. Soluble salts are often placed around a ground rod to increase the conductivity of the soil and thus lower its resistance. If the resistance to earth increases, this could indicate that the salts are being leached away and replenishment is necessary. Soil moisture affects the functioning of the grounding system; if resistance increases, this could indicate a decrease in moisture content (perhaps a lowering of the water table), making necessary a longer ground rod to reach a moist soil stratum.

RESULTS

The values of the potential, resistance-to-earth, and current flow measurements made during the test period are presented graphically in Appendix A.

Potentials

The potentials of the single rods (Figure 1-A, Appendix A) were not particularly constant during the first year. After that all potentials were relatively constant except for one date when several rapidly decreased* and equally abruptly increased to about the same value as before. An exception was the potential of the stainless steel rod, which showed an overall variation of 340 millivolts (mv) during the first year and approximately 200 mv during the last two years. The galvanized rod's potential changed by 280 mv during the first six months and then generally paralleled closely the mild steel rod's potential.

The potentials of four of the eight couples (Figure 2-A) were quite close and relatively constant for the entire test period. These were mild steel coupled to copperclad (two couples), Ni-Resist, and stainless steel. In these cases the mild steel is a sacrificial anode for the other metal in the couple. The potential of the aluminum couple was somewhat higher but was even more constant than these four.

The potential of the couple including a galvanized rod was essentially stable for two weeks, but then decreased quite rapidly for a month followed by a continuous, but less rapid decline for four more months. At that point the potential was almost that of the four couples cited earlier; soon after, its potential was essentially the same as those of the four couples.

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*All potential values are negative with respect to a copper sulfate half-cell. A higher value of potential, or an increase in potential means more negative with respect to the half-cell.

The potentials of the two zinc couples decreased rapidly during the first two weeks and then remained relatively stable for ten months. Both increased over the next month almost to their initial value, and remained there for almost four months. Both potentials then decreased to values nearly the same as their previous low levels; after that the potentials generally increased.

Current Flow

The current flow in the various couples (Figure 3-A) has generally followed a decreasing trend, with varying degrees of irregularity. The greatest overall variations in current flow have been in the couple consisting of a copperclad steel rod and two mild steel rods (32.5 milliamperes), and in the galvanized steel - mild steel couple (29.7 ma). The least current flow was generally found in the stainless steel couple, with the Ni-Resist couple showing the next least.

Resistance

The resistance to earth of five of the single rods (Figure 4-A) were quite close to each other during the test period. The exceptions were the resistances of rods of zinc and magnesium. The zinc rod's resistance was quite high initially but dropped abruptly after ten months; it remained low (in the general range of the five rods) for about seven months, averaged about 15 ohms for the next fifteen months, and then underwent a sharp decline. The magnesium rod's resistance followed the path of the group of five for fourteen months, after which it increased very abruptly by 17 ohms in a week. The resistance continued to increase, with irregularities, until reaching 88 ohms at the end of the test.

Resistance values of the coupled rods (Figure 5-A) generally followed mutually similar paths, with the galvanized rod couple as an early exception. Its initial resistance of 6.2 ohms was one and one-half times the next highest, and increased in five months to about 12.5 ohms or nearly three times the next highest. From that point the resistance dropped quite rapidly, and followed those of the other couples. For the most part it maintained the highest value for the remainder of the test.

Weight Losses

The weight losses of the various rods are given in Table 1 along with calculated corrosion rates. For single rods, stainless steel had the least percent weight loss, followed in increasing order by copperclad steel, zinc, aluminum, galvanized steel, mild steel, and magnesium. The weight loss of the copperclad rods is attributable to corrosion of the mild steel core; copper corrosion was negligible.

The effect produced by coupling the various metals to one or more mild steel rods is demonstrated by comparing the corrosion rates for the single rods to those in couples. Coupling to copperclad steel resulted in a 143 percent increase in the corrosion rate of a mild steel rod; two mild steel rods developed an average increase in corrosion rate per rod

of 94 percent. The corrosion rate for the copperclad steel was reduced by 62 percent and 65 percent by coupling to one and two mild steel rods respectively.

Coupling Ni-Resist to mild steel produced a corrosion rate decrease of 81 percent* for the former and an increase of 22 percent for the latter. With stainless steel in place of Ni-Resist, the respective changes were a 75 percent decrease for stainless and an 11 percent increase for mild steel. Galvanized steel caused a 53 percent decrease for the mild steel, but at a 169 percent increase in its own rate. The corrosion rates for the mild steel were reduced by 92 and 87 percent by aluminum and zinc, whose rates were increased to 12.7 and 10.5 times those for uncoupled rods. The corrosion rate for the zinc rod, when coupled to two mild steel rods was increased to 16.3 times that for an uncoupled rod; the rates for the mild steel rods were reduced by an average of 86 percent.

DISCUSSION

Three factors determine the acceptability of a grounding system: (1) its resistance to earth; (2) its effect on the corrosion rate of other buried metals; and (3) its electrical conductivity. These factors depend on several others, such as moisture in the soil, particle size, dissolved solids, degree of aeration, the grounding requirements of a structure, and properties directly related to the metal in the grounding system and any other buried metal which might be involved.

Based on the resistance-to-earth data for single rods in the three-year group at the NCEL site, copperclad steel is the best metal for use in a grounding system. Next are stainless steel, mild steel, aluminum, galvanized steel, magnesium, and zinc. The order of preferability for the one year group was stainless steel, aluminum, magnesium, galvanized steel, mild steel, copperclad steel, and zinc, also based on resistance-to-earth data. These metals would be acceptable for grounding in a similar location, if properly used, except magnesium and zinc which corrode rapidly in providing cathodic protection to buried metals with which they might form an electrical circuit. Mild steel and galvanized steel, when used, should have cathodic protection.**

Current flow measurements indicated that the mild steel rods were serving as sacrificial anodes for copperclad steel, Ni-Resist, and stainless steel, and as a cathode for aluminum, magnesium and zinc. Potential measurements indicated a low potential for couples incorporating the first group of metals, and an acceptably or excessively high potential for couples with the other metals except the aluminum couple. Its potential was somewhat lower than that generally considered safe for a structure incorporating steel.

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* Based on the corrosion rate of the single Ni-Resist rod in the one year group; as noted earlier, the single Ni-Resist rod in the three-year group broke during driving.

** Corrosion Prevention and Control, NAVDOCKS MO-306, Section 11.2.3.5, page 219.

The weight losses and corrosion rates of the three-year group should be compared to the corresponding results from the one-year group. Data on single rods generally reveal a decrease in percent loss per year, with a corresponding decrease in the corrosion rate. One exception is the magnesium rod, whose percent loss per year increased by more than four times over the test period. This may have been caused by the dense corrosion product that formed around the rod. The product adhered tightly to the rod, and by retaining moisture permitted a ready flow of current from one point on the residual metal to another. The corrosion rate may have been accelerated because of this favorable condition.

The coupled rods also generally show a decrease in weight loss per year, with a decrease in corrosion rate. Exceptions are the steel rods coupled to copperclad and to Ni-Resist, showing a slight increase in the percent loss per year.

The results generally indicate that after an initial period of rapid corrosion the rate of corrosion will diminish. That is somewhat comparable to the corrosion of many metals in sea water, where the same phenomenon is often evident.

The performance of the stainless steel rod provides a further confirmation of its value for grounding. A point of interest is that the City of Los Angeles Department of Water and Power in 1965 started a program using Type 304 stainless steel-clad rods for installations such as transformer pad mounts. The decision to make this change was based on the excellent performance of stainless steel in the Los Angeles area and elsewhere across the country. Eight-foot rods are available for $3.65 each in lots of 200; the LADWP is now using its third lot. Two factors tend to minimize the present cost advantage of copperclad rods: the stainless steel rods have a minor effect on the service life of buried steel, where copper causes severe attack; the price of copper is increasing and a similar increase may be expected for copperclad ground rods. Types 302 and 304 stainless steel are both very similar in composition, and are representative of the 300 series of stainless steels. The entire 300 series is expected to perform similarly, but Types 302 and 304 are among the least expensive of the group.

CONCLUSIONS AND RECOMMENDATIONS

1. Stainless steel, or stainless-clad rods are superior to existing ground rods on the basis of resistance-to-earth and weight-loss data. Rods made from the 300 series of stainless steels are recommended for grounding.

2. The results of the one-year tests have been confirmed, at least in part, by basically similar resistance and weight-loss data. It is recommended that the test program be continued for the full seven years to insure that the relative positions of the metals under test remains unchanged.

WEIGHT CHANGES AND CORROSION RATES OF DRIVEN GROUND RODS

Rod Number	Metal	Use	Three-Year Group: Initial Weight	Three-Year Group: Final Weight	Three-Year Group: Weight Loss	Three-Year Group: Loss %	Three-Year Group: Corr. Rate gm/cm²/yr	One-Year Group: Wt. Loss %	One-Year Group: Corr. Rate gm/cm²/yr
31	I	Single Rod	3749gm	3520gm	229gm	6.11	.0629	2.56	.0736
32	G	Single Rod	3625	3539	86	2.37	.0239	1.54	.0435
33	C	Single Rod	3451	3419	32 2/	.927	.00895	.52	.0147
34	N	Broken during installation						.68	.0195
35	S	Single Rod	3833	3813	20	.532	.00548	.18	.0053
36	I	(Removed after one year; originally coupled to 49M)							
37	I	Coupled to 40N	3740	3461	279	7.46	.0766	2.41	.0642
38	I	Coupled to 41S	3753	3498	255	6.79	.0700	2.53	.0727
39	C	Coupled to 45I	3452	3440	12 3/	.348	.00336	.38	.0106
40	N	Coupled to 37I	3992	3978	14	.351	.00369	.26	.0073
41	S	Coupled to 38I	3795	3790	5	.132	.00137	.052	.0015
42	A	Single Rod	1302	1281	21	1.61	.00575	.92	.0091
43	M	Single Rod	851	213	638	74.97	.1747	6.31	.0412
44	Z	Single Rod	3423	3381	42	1.23	.0115	1.20	.0314
45	I	Coupled to 39C	3761	3205	556	14.78	.1527	4.83	.138
46	I	Coupled to 48A	3749	3729	20	.533	.00549	1.02	.0291
47	I	Coupled to 50G	3760	3653	107	2.85	.0294	1.22	.0351
48	A	Coupled to 46I	1300	1034	266	20.46	.0729	7.35	.0734
49	M	(Removed after one year; originally coupled to 36I)							
50	G	Coupled to 47I	3702	3471	231	6.24	.0643	3.72	0.105
51	I	Coupled to 57C	3744	3360	384	10.26	.1054	3.83	0.110
52	I	Coupled to 57C	3757	3254	503	13.39	.1382	3.57	0.103
53	I	(Removed after one year; originally coupled to 58M)							
54	I	(Removed after one year; originally coupled to 58M)							
55	I	Coupled to 59Z	3751	3717	34	.906	.00934	.89	0.0252
56	I	Coupled to 59Z	3752	3723	29	.773	.00796	.72	0.0206
57	C	Coupled to 51I & 52I	3481	3470	11 4/	.316	.00308	.35	0.0097
58	M	(Removed after one year; originally coupled to 53I & 54I)							
59	Z	Coupled to 55I & 56I	3417	2730	687	20.11	.1889	8.32	0.217
60	Z	Coupled to 92I	3413	2971	442	12.95	.1215	6.88	0.179
92	I	Coupled to 60Z	3760	3729	31	.824	.00851	.88	.0252

1/ I = Mild Steel; G = Galvanized Steel; C = Copperclad Steel; N = Ni-Resist; S = Type 302 Stainless Steel; A = 6061-T6 Aluminum Alloy; M = AZ31B Magnesium Alloy; Z = High-Purity Zinc

2/ 1 3/16" of steel core lost

3/ 1/4" of steel core lost

4/ 1/8" of steel core lost

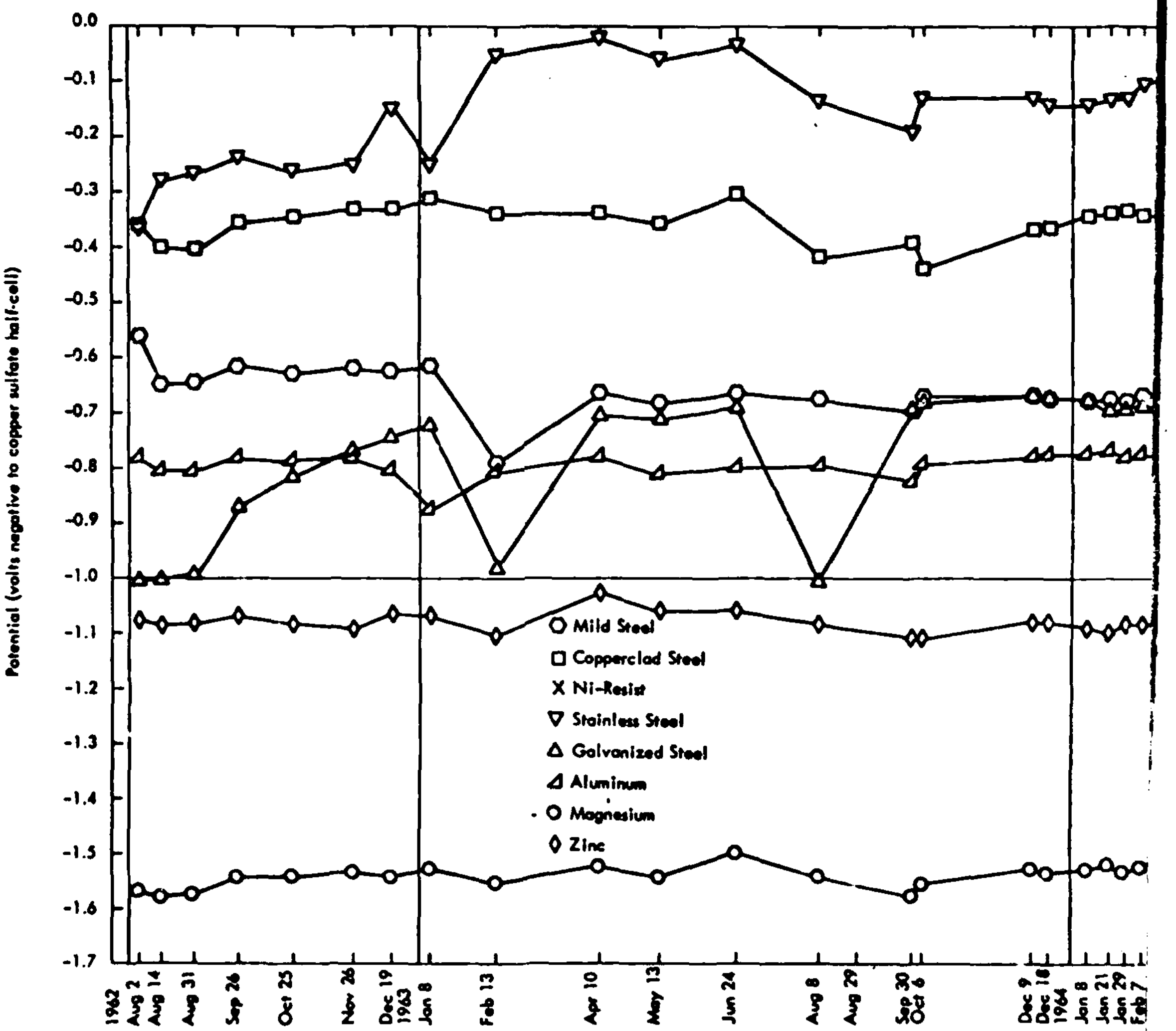


Figure 1A. Potential of Si

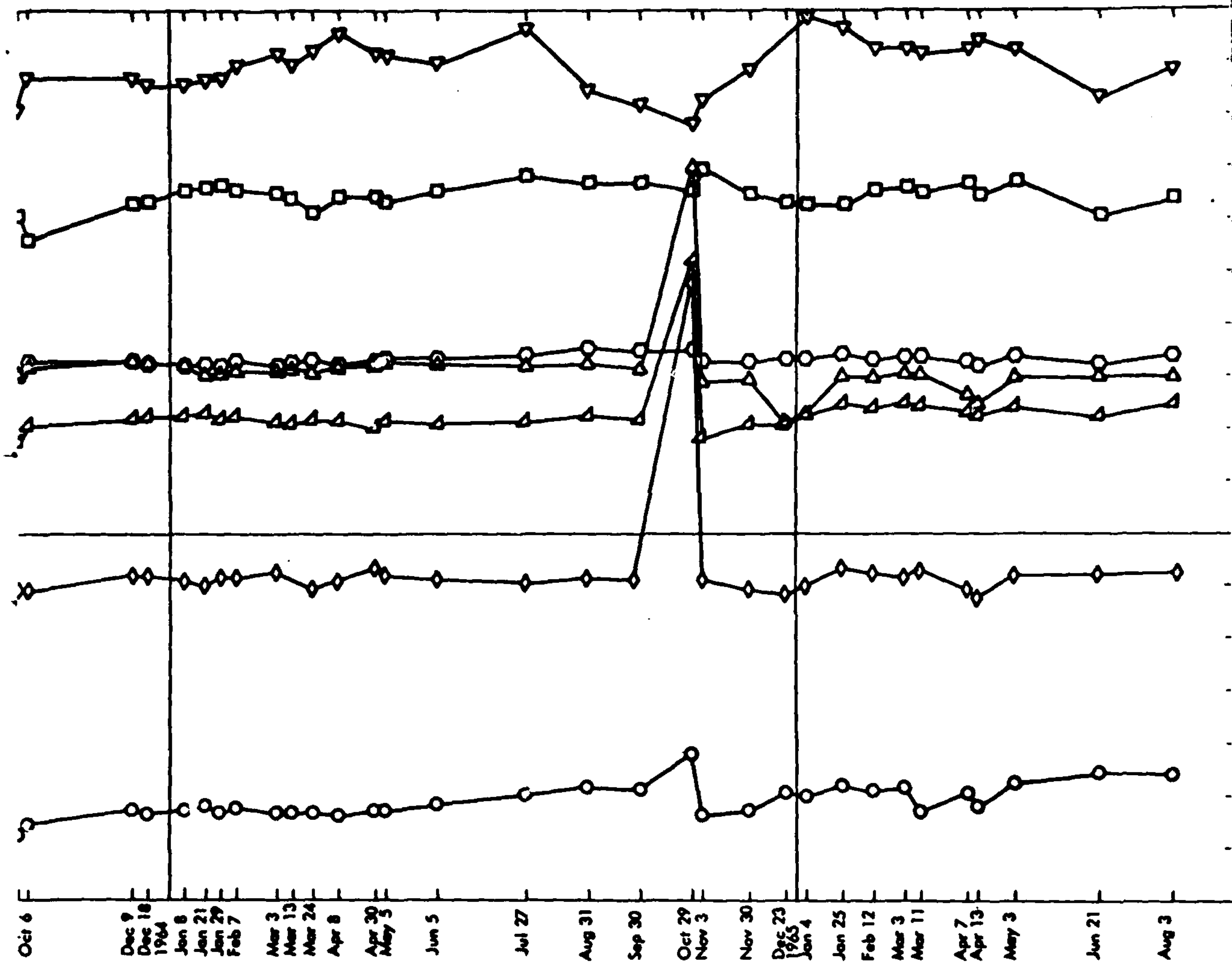


Figure 1A. Potential of Single Rods, NCEL Site

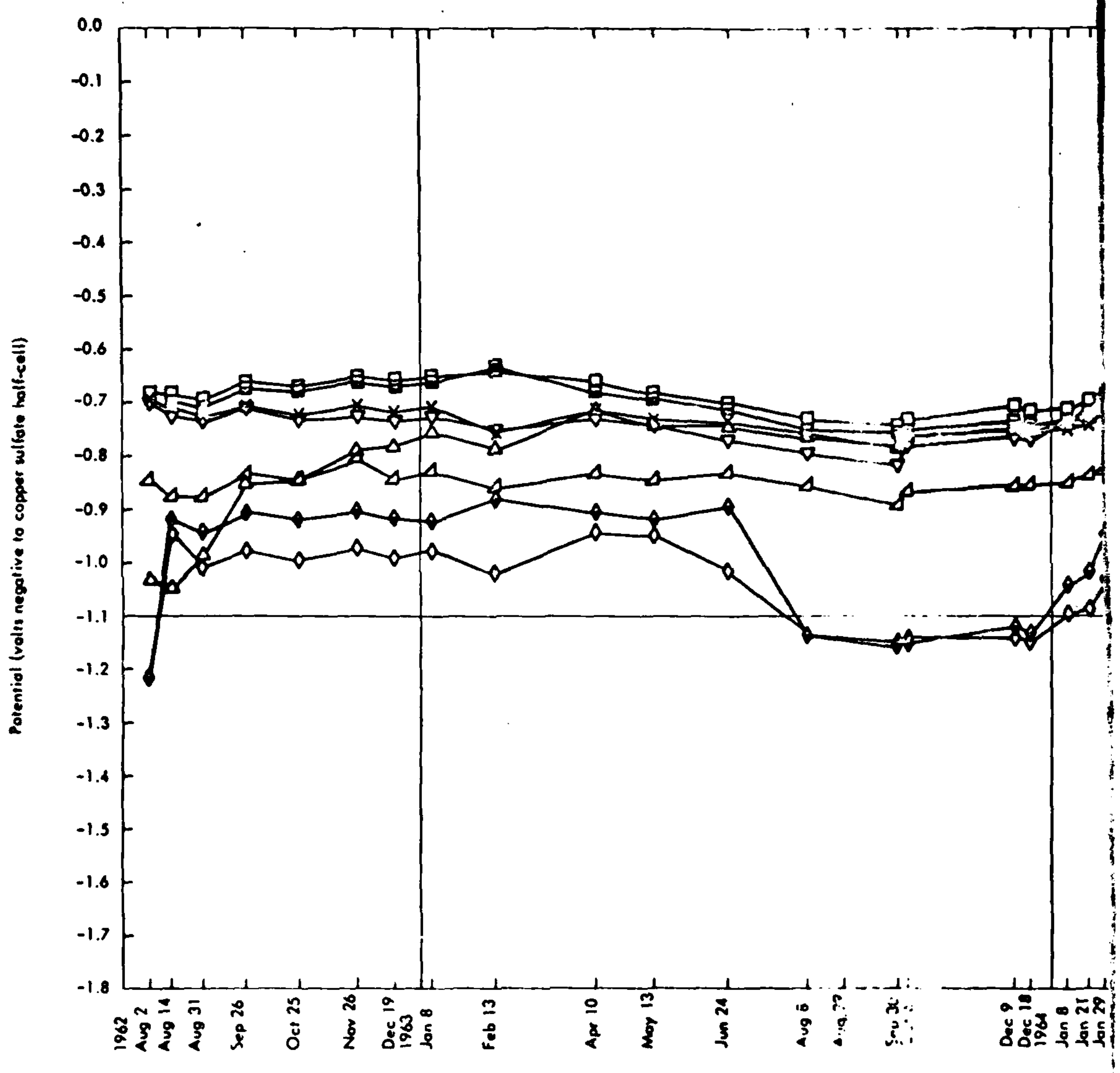
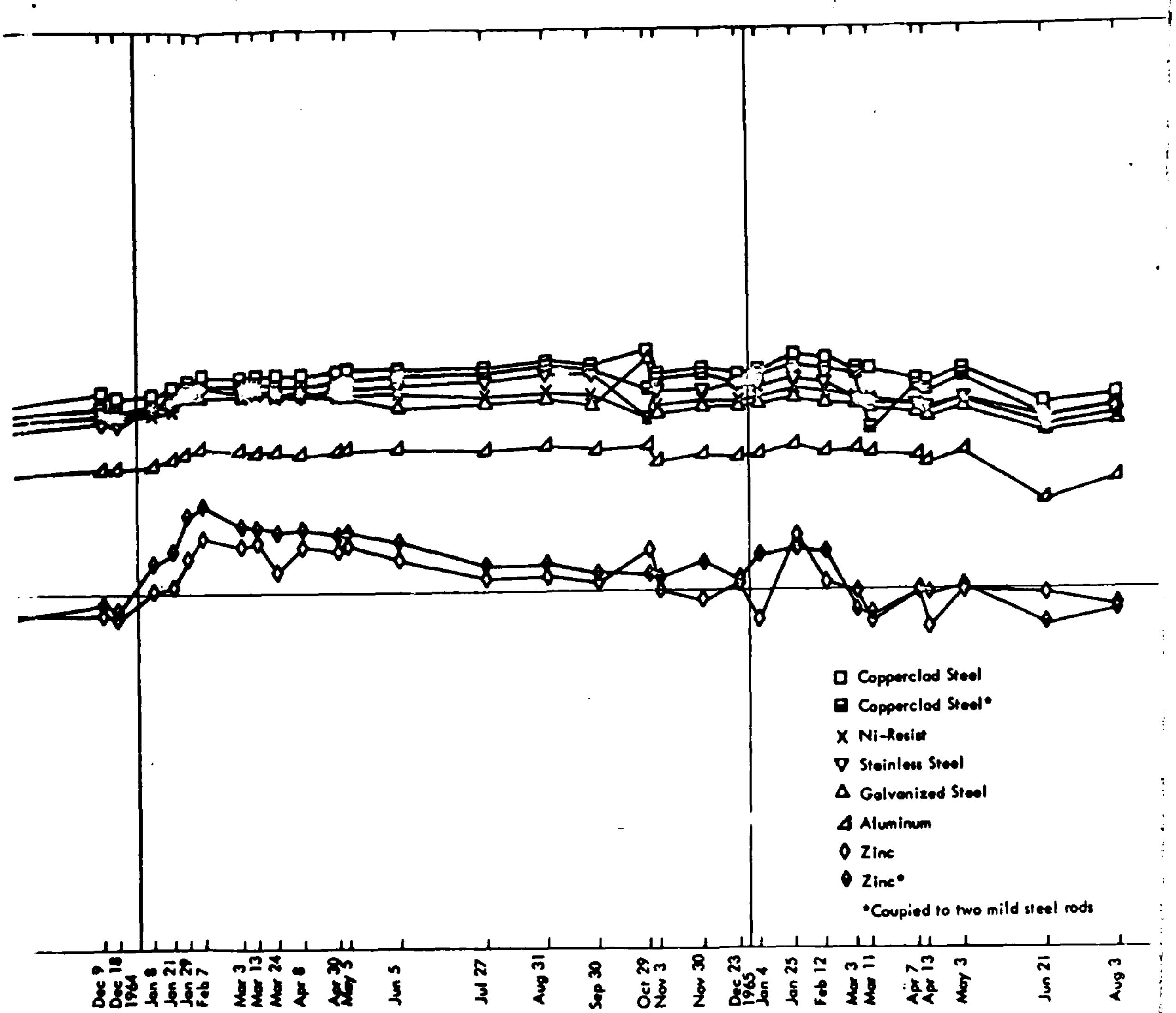


Figure 2A. ...tial of Coupled Rods, N



tial of Coupled Rods, NCEL Site

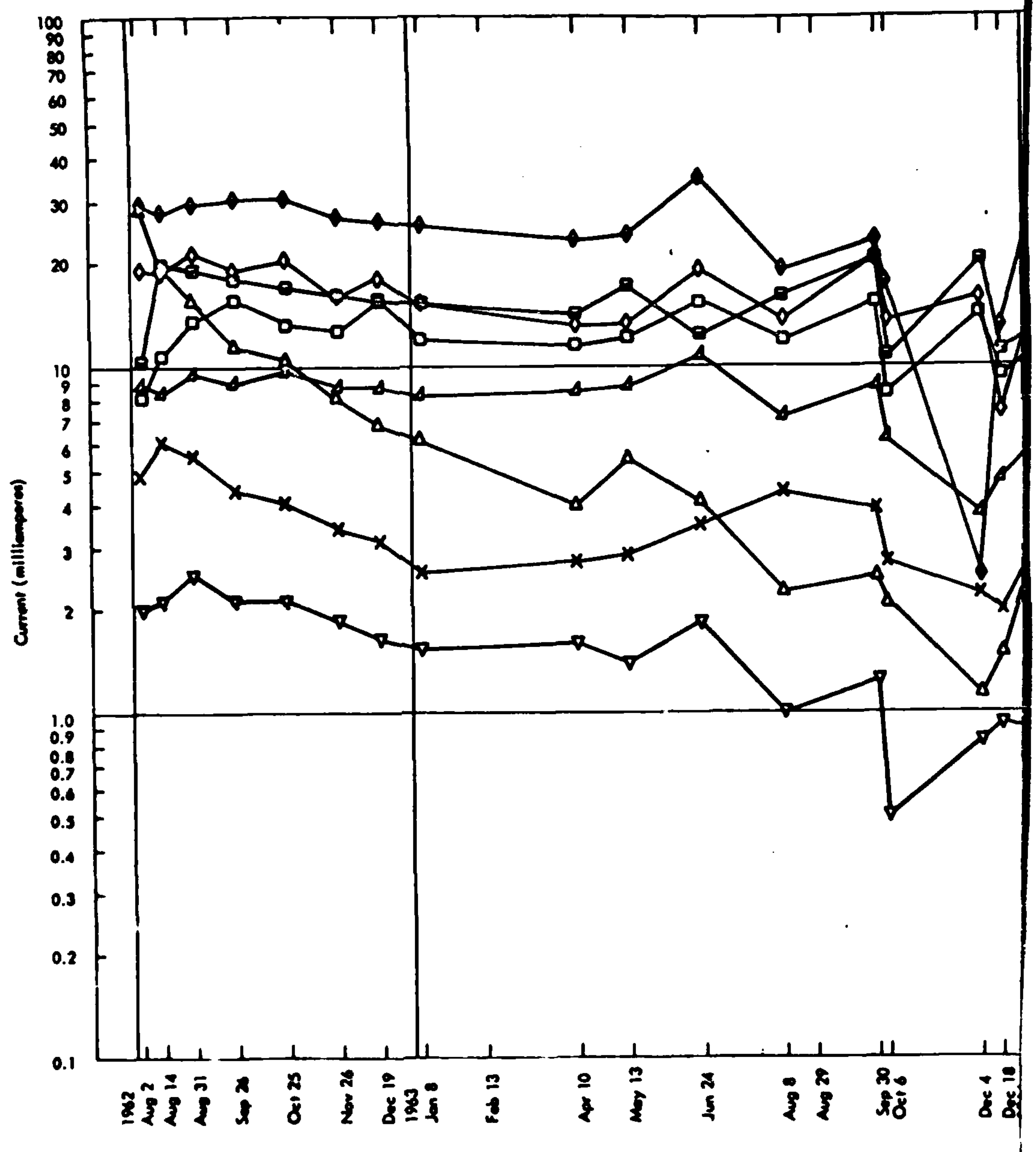
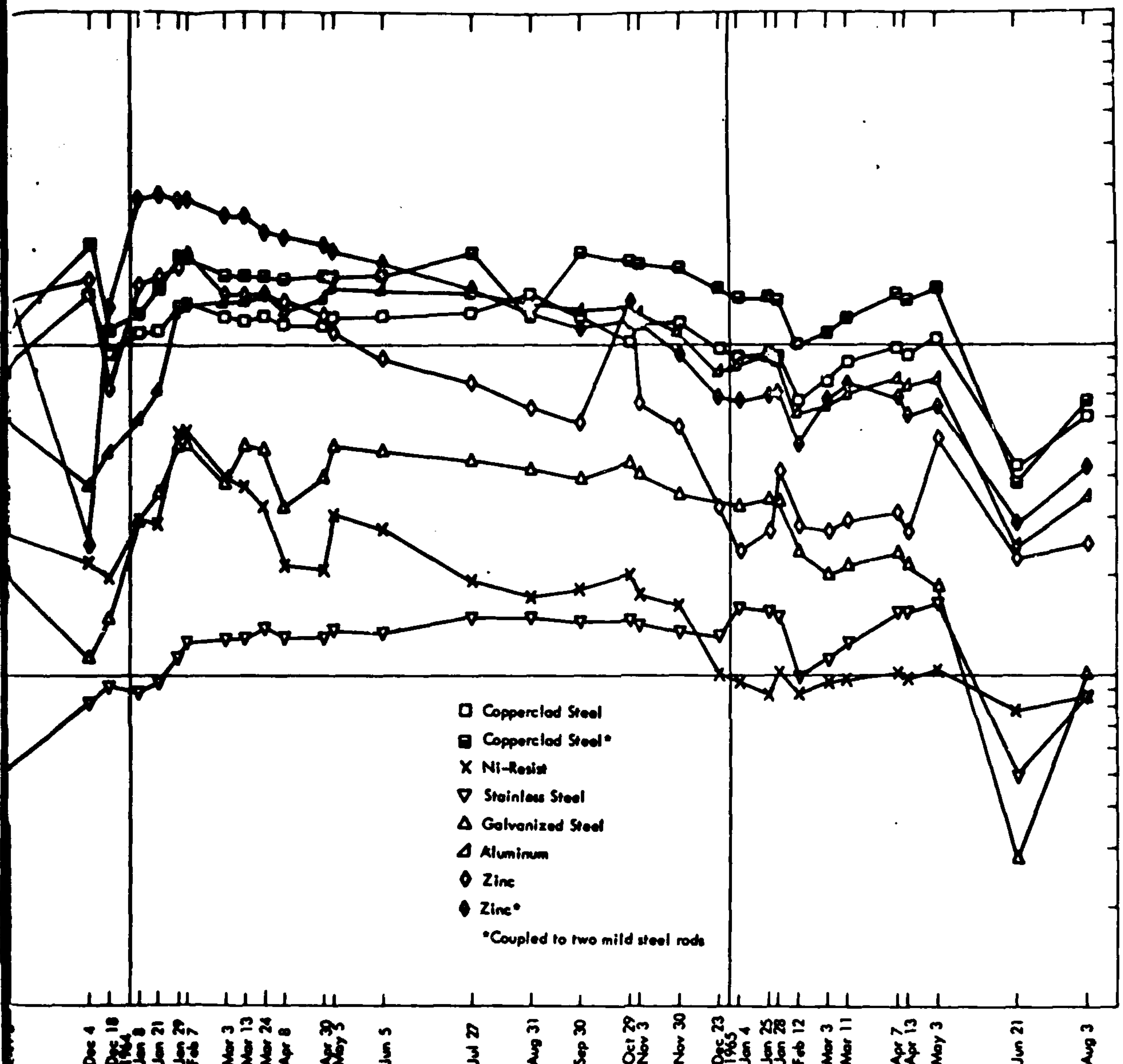


Figure 3A. Current Flow



. Current Flow in Couples, NCEL Site, 3-year group

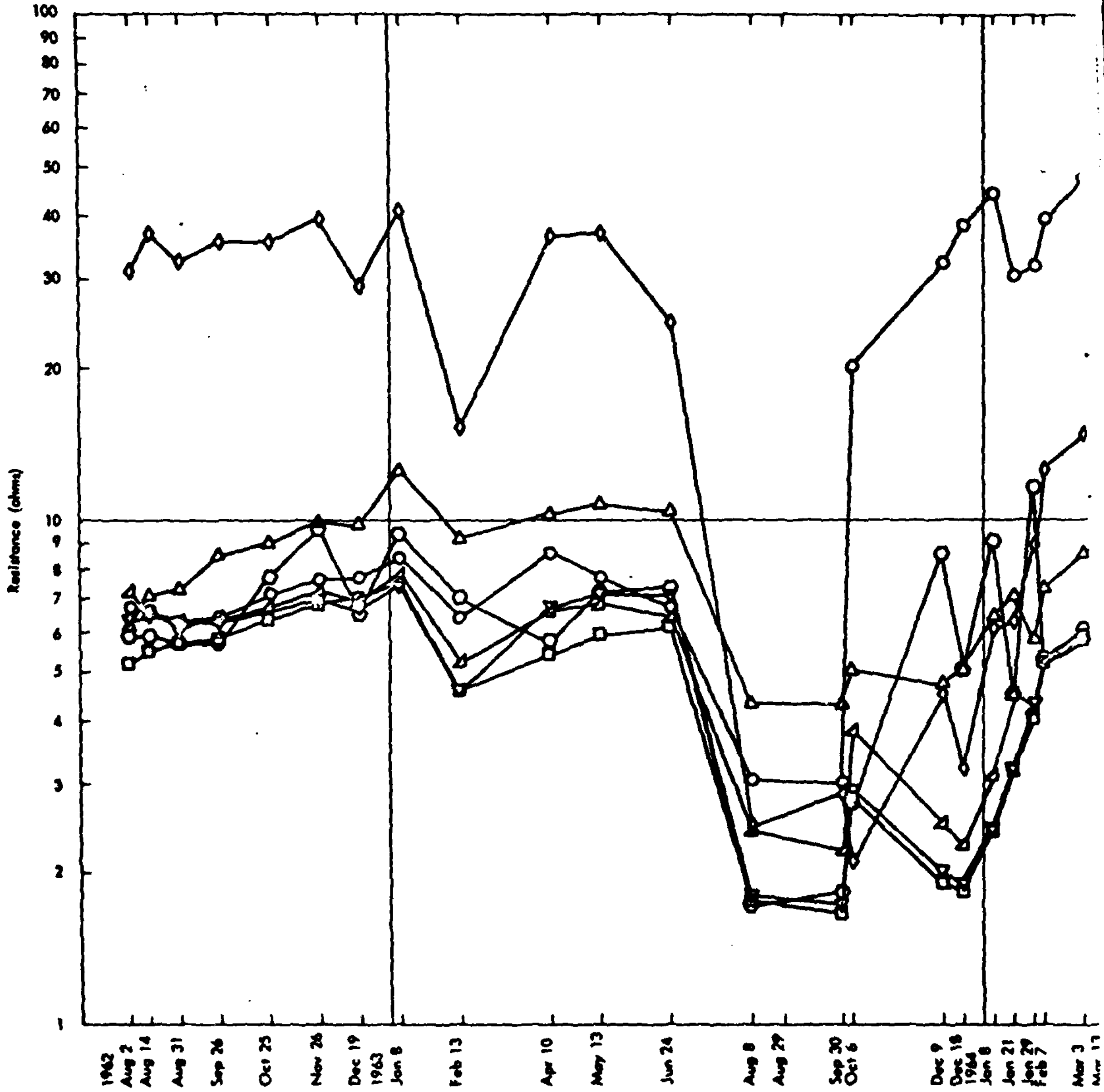
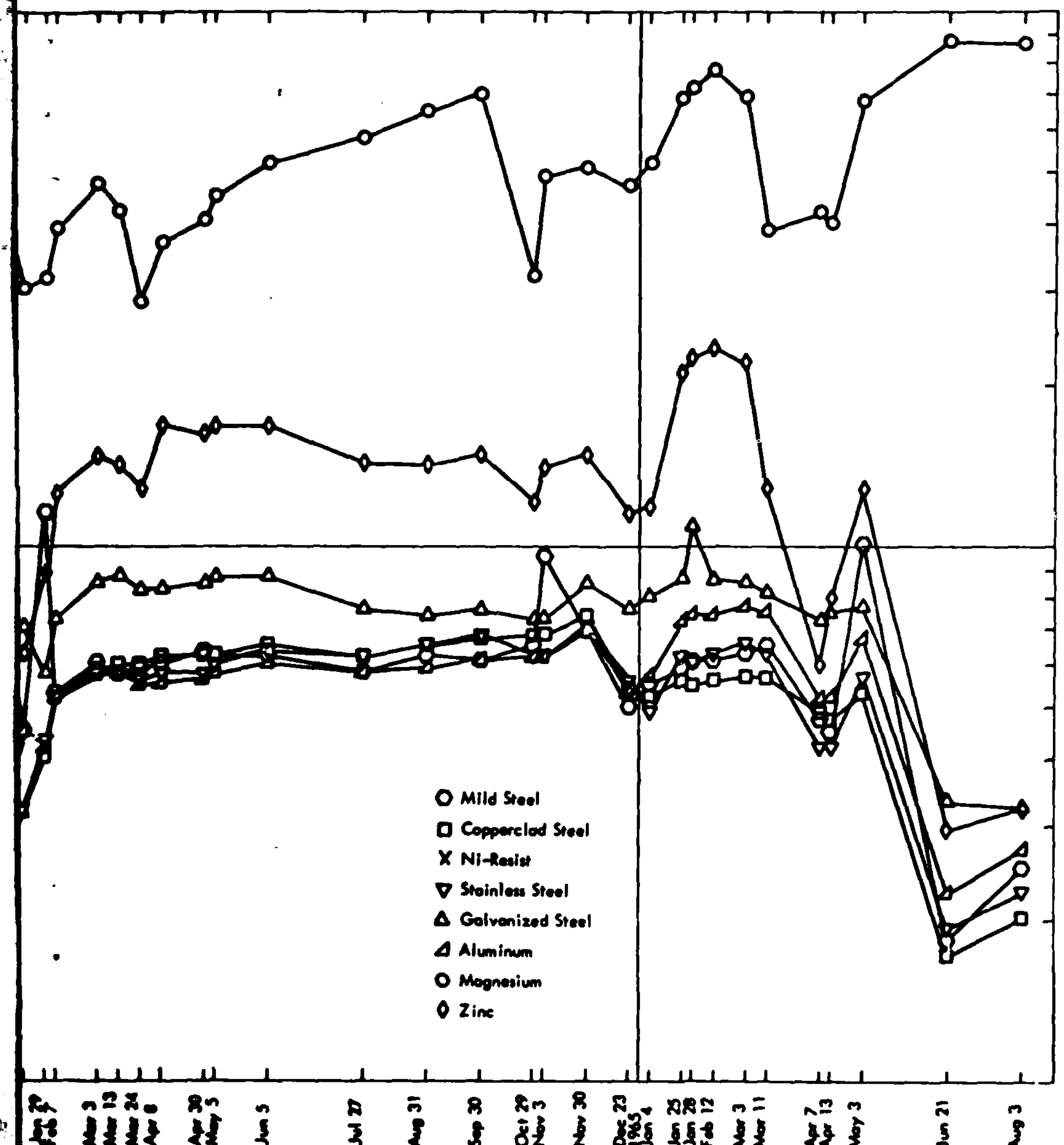
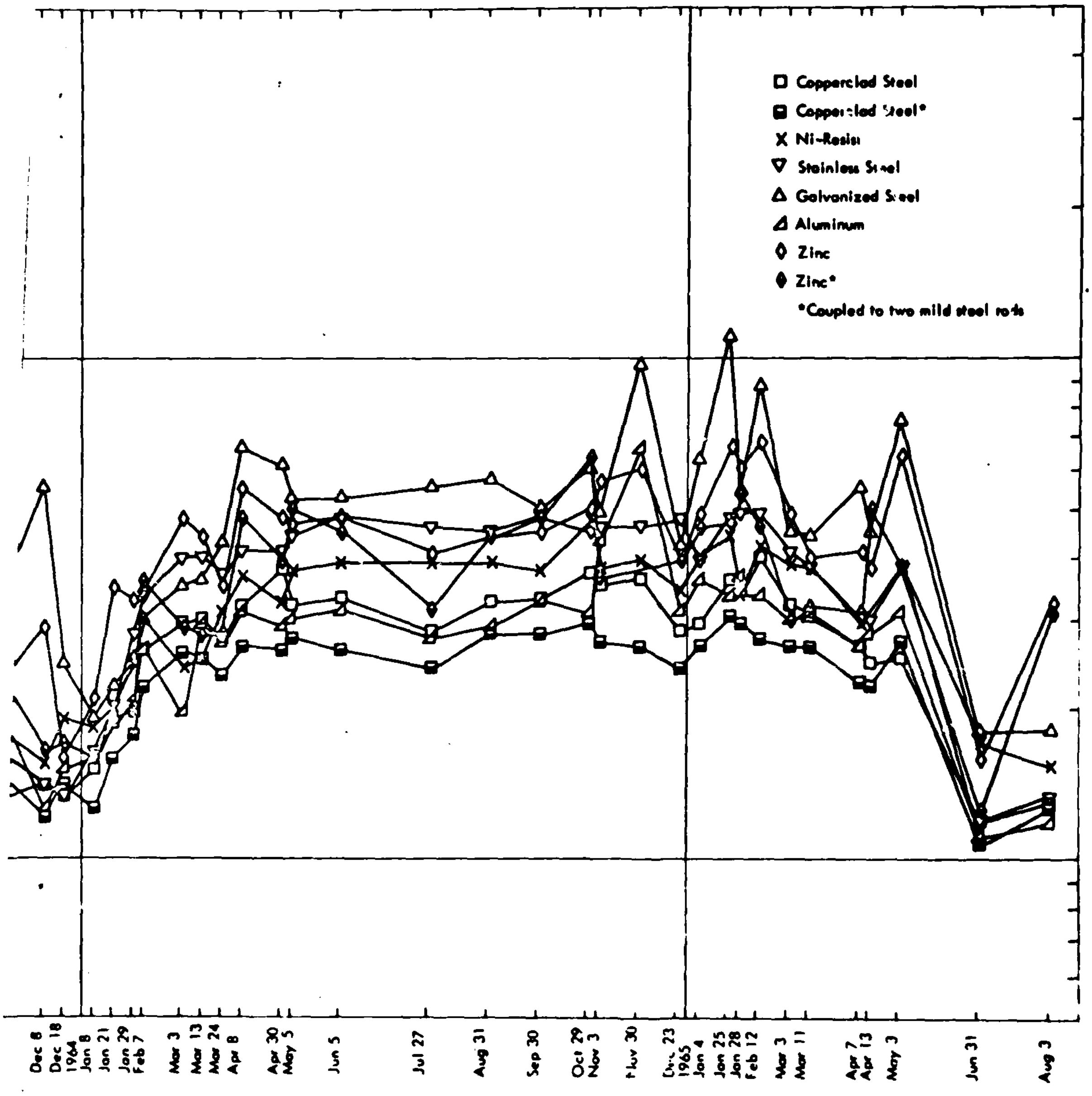


Figure 4A. Resistance to Ground



...s to Ground of Single Rods, NCEL Site



Ground of Coupled Rods — NCEL Site — 3 year group

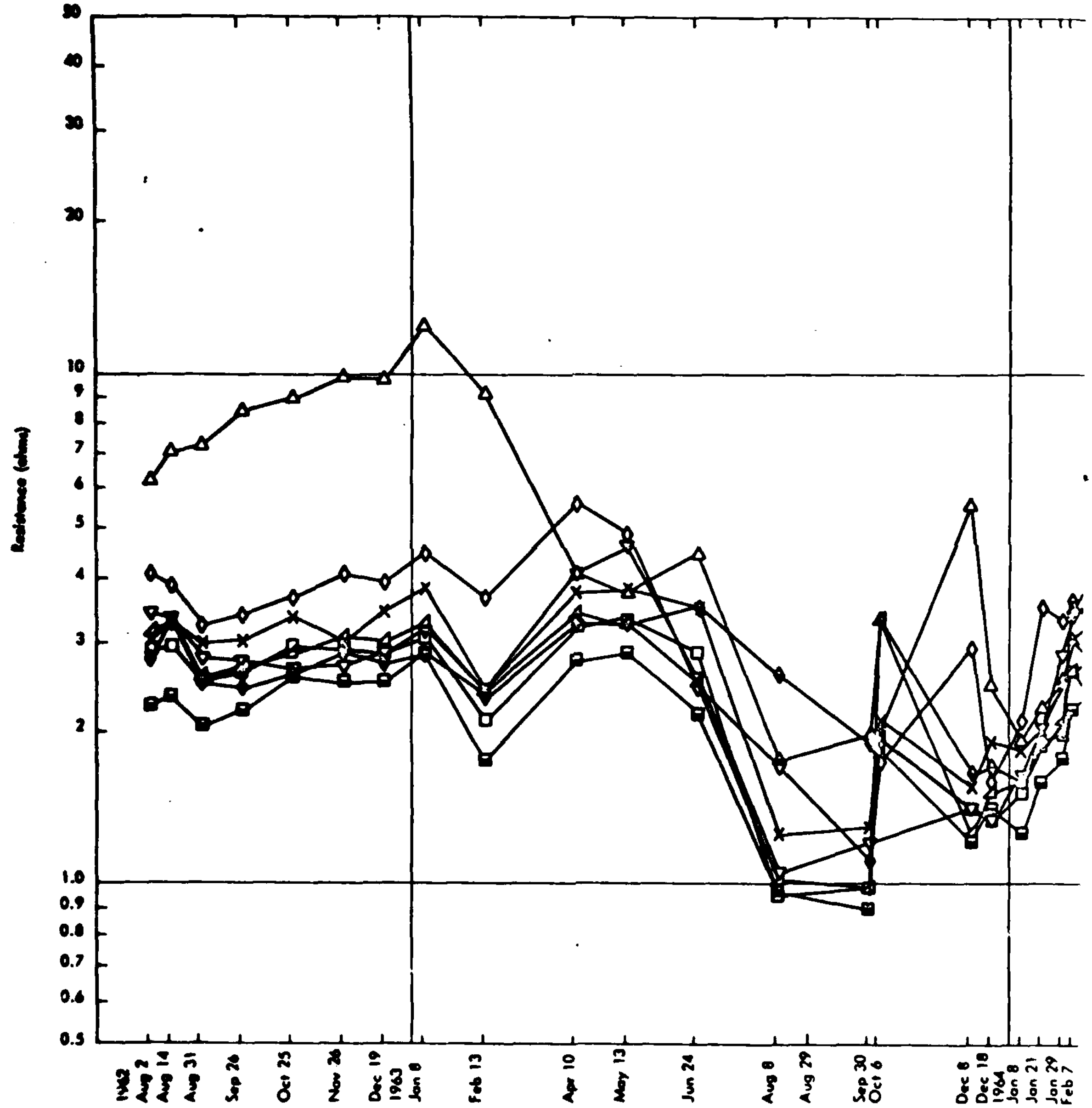


Figure 5A. Resistance to Ground of Coupled Ro